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7. INHALATION ROUTE

7.1 INTRODUCTION

This chapter presents data and recommendations for inhalation rates that can be used to assess children's exposure to contaminants in air. Children may be more highly exposed to environmental toxicants through inhalation routes than adults. Infants and young children have a higher resting metabolic rate and rate of oxygen consumption per unit body weight than adults because they have a larger cooling surface per unit body weight and because they are growing rapidly. The oxygen consumption of a resting infant aged between one week and one year is 7 ml/kg body weight per minute. The rate for an adult under the same conditions is 3-5 ml/kg per minute (WHO 1996). Thus, the volume of air passing through the lungs of a resting infant is twice that of a resting adult under the same conditions and therefore twice as much of any chemical in the atmosphere could reach the lungs of an infant. The recommended inhalation rates for children are summarized in Section 7.3.

7.2 INHALATION RATE STUDIES

Linn et al. (1992) - Documentation of Activity Patterns in "High-Risk" Groups Exposed to Ozone in the Los Angeles Area - Linn et al. (1992) conducted a study that estimated the inhalation rates for "high-risk" subpopulation groups exposed to ozone (O_3) in their daily activities in the Los Angeles area. The population surveyed consisted of several panels of both adults and children. The panels consisting of children included: *Panel 2*: 17 healthy elementary school students (5 males, 12 females, ages 10-12 years); *Panel 3*: 19 healthy high school students (7 males, 12 females, ages 13-17 years); *Panel 6*: 13 young asthmatics (7 males, 6 females, ages 11-16 years).

Initially, a calibration test was conducted, followed by a training session. Finally, a field study was conducted which involved subjects' collecting their own heart rate and diary data. During the calibration tests, ventilation rate (VR), breathing rate, and heart rate (HR) were measured simultaneously at each exercise level. From the calibration data an equation was developed using linear regression analysis to predict VR from measured HR (Linn et al., 1992).

In the field study, each subject recorded in diaries: their daily activities, change in locations (indoors, outdoors, or in a vehicle), self-estimated breathing rates during each activity/location, and time spent at each activity/location. Healthy subjects recorded their HR once every 60 seconds, Asthmatic subjects recorded their diary information once every hour using a Heart Watch. Subjective breathing rates were defined as slow (walking at their normal pace); medium (faster than normal walking); and fast (running or similarly strenuous exercise). Table 7-1 presents the calibration and field protocols for self-monitoring of activities for each subject panel.

Table 7-2 presents the mean VR, the 99th percentile VR, and the mean VR at each subjective activity level (slow, medium, fast). The mean VR and 99th percentile VR were derived from all HR recordings (that appeared to be valid) without considering the diary data. Each of the three activity levels was determined from both the concurrent diary data and HR recordings by direct calculation or regression (Linn et al., 1992). Linn et al. (1992) reported that the diary data showed that most individuals spent most of their time (in a typical day) indoors at slow activity level. During slow activity, asthmatic subjects had higher VRs than healthy subjects, (Table 7-2). Also, Linn et al. (1992) reported that in every panel, the predicted VR correlated significantly with the subjective estimates of activity levels.

A limitation of this study is that calibration data may overestimate the predictive power of HR during actual field monitoring. The wide variety of exercises in everyday activities may result in greater variation of the VR-HR relationship than calibrated. Another limitation of this study is the small sample size of each subpopulation surveyed. An advantage of this study is that diary data can provide rough estimates of ventilation patterns which are useful in exposure assessments. Another advantage is that inhalation rates were presented for both healthy and asthmatic children.

Spier et al. (1992) - Activity Patterns in Elementary and High School Students Exposed To Oxidant Pollution - Spier et al. (1992) investigated activity patterns of 17 elementary school students (10-12 years old) and 19 high school students (13-17 years old) in suburban Los Angeles from late September to October (oxidant pollution season). Calibration tests were conducted in supervised outdoor exercise sessions. The exercise sessions consisted of 5 minutes for each: rest, slow walking, jogging, and fast walking. HR and VR were measured during the last 2 minutes of each exercise. Individual VR and HR relationships for each individual were determined by fitting a regression line to HR values and log VR values. Each subject recorded their daily activities, change in location, and breathing rates in diaries for 3 consecutive days. Self-estimated breathing rates were recorded as slow (slow walking), medium (walking faster than normal), and fast (running). HR was recorded during the 3 days once per minute by wearing a Heart Watch. VR values for each self-estimated breathing rate and activity type were estimated from the HR recordings by employing the VR and HR equation obtained from the calibration tests.

The data presented in Table 7-3 represent HR distribution patterns and corresponding predicted VR for each age group during hours spent awake. At the same self-reported activity levels for both age groups, inhalation rates were higher for outdoor activities than for indoor activities. The total hours spent indoors by high school students (21.2 hours) were higher than for elementary school students (19.6 hours). The converse was true for outdoor activities; 2.7 hours for high school students, and 4.4 hours for elementary school students (Table 7-4). Based on the data presented in Tables 7-3 and 7-4, the average activity-specific inhalation rates for elementary (10-12 years) and high school (13-17 years) students were calculated in Table 7-5. For elementary school students, the average daily inhalation rates (based on indoor and outdoor locations) are 15.8 m^3/day for light activities, 4.62 m^3/day for moderate activities, and 0.98 m^3/day for heavy activities. For high school students the daily inhalation rates for light, moderate, and heavy activities are estimated to be 16.4 m^3/day, 3.1 m^3/day, and 0.54 m^3/day, respectively (Table 7-5).

A limitation of this study is the small sample size. The results may not be representative of all children in these age groups. Another limitation is that the accuracy of the self-estimated breathing rates reported by younger age groups is uncertain. This may affect the validity of the data set generated. An advantage of this study is that inhalation rates were determined for children and adolescents. These data are useful in estimating exposure for the younger population.

Adams (1993) - Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities - Adams (1993) conducted research to accomplish two main objectives: (1) identification of mean and ranges of inhalation rates for various age/gender cohorts and specific activities; and (2) derivation of simple linear and multiple regression equations used to predict inhalation rates through other measured variables: breathing frequency (f_B) and oxygen consumption (V_{O2}). A total of 160 subjects participated in the primary study. For children, there were two age dependent groups: (1) children 6 to 12.9 years old, (2) adolescents between 13 and 18.9 years old, (Adams, 1993). An additional 40 children from 6 to 12 years old and 12 young children from 3 to 5 years old were identified as subjects for pilot testing purposes (Adams, 1993).

Resting protocols conducted in the laboratory for all age groups consisted of three phases (25 minutes each) of lying, sitting, and standing. They were categorized as resting and sedentary activities. Two active protocols, moderate (walking) and heavy (jogging/ running) phases, were performed on a treadmill over a progressive continuum of intensities made up of 6 minute intervals, at 3 speeds, ranging from slow to moderately fast. All protocols involved measuring VR, HR, f_B (breathing frequency), and V_{O2} (oxygen consumption). Measurements were taken in the last 5 minutes of each phase of the resting protocol, and the last 3 minutes of the 6 minute intervals at each speed designated in the active protocols.

In the field, all children completed spontaneous play protocols, while the older adolescent population (16-18 years) completed car driving and riding, car maintenance (males), and housework (females) protocols.

During all activities in either the laboratory or field protocols, IR for the children's group revealed no significant gender differences. Therefore, IR data presented in Appendix Tables 7A-1 and 7A-2 were categorized as young children, children (no gender) by activity levels (resting, sedentary, light, moderate, and heavy). These categorized data from the Appendix tables are summarized as IR in m^3/hr in Tables 7-6 and 7-7. The laboratory protocols are shown in Table 7-6. Table 7-7 presents the mean inhalation rates by group and activity levels (light, sedentary, and moderate) in field protocols. Accurate predictions of IR across all population groups and activity types were obtained by including body surface area (BSA), HR, and f_B in multiple regression analysis (Adams, 1993). Adams (1993) calculated BSA from measured height and weight using the equation:

$$BSA = Height^{(0.425)} \times Weight^{(0.425)} \times 71.84 \qquad (7\text{-}1)$$

A limitation associated with this study is that the population does not represent the general U.S. population. Also, the classification of activity types (i.e., laboratory and field protocols) into activity levels may bias the inhalation rates obtained for various age/gender cohorts. The estimated rates were based on short-term data and may not reflect long-term patterns.

Layton (1993) - Metabolically Consistent Breathing Rates for Use in Dose Assessments - Layton (1993) presented a new method for estimating metabolically consistent inhalation rates for use in quantitative dose assessments of airborne radionuclides. Generally, the approach for estimating the breathing rate for a specified time frame was to calculate a time-weighted-average of ventilation rates associated with physical activities of varying durations (Layton, 1993). However, in this study, breathing rates were calculated based on oxygen consumption associated with energy expenditures for short (hours) and long (weeks and months) periods of time, using the following general equation to calculate energy-dependent inhalation rates:

$$V_E = E \times H \times VQ \qquad (7\text{-}2)$$

where:

V_E = ventilation rate (L/min or m^3/hr);

E = energy expenditure rate; [kilojoules/minute (KJ/min) or megajoules/hour (MJ/hr)];

H = volume of oxygen [at standard temperature and pressure, dry air (STPD) consumed in the production of 1 kilojoule (KJ) of energy expended (L/KJ or m^3/MJ)]; and

VQ = ventilatory equivalent (ratio of minute volume (L/min) to oxygen uptake (L/min)) unitless.

Three alternative approaches were used to estimate daily chronic (long term) inhalation rates for different age/gender cohorts of the U.S. population using this methodology.

First Approach

Inhalation rates were estimated by multiplying average daily food energy intakes for different age/gender cohorts, volume of oxygen (H), and ventilatory equivalent (VQ), as shown in the equation above. The average food energy intake data (Table 7-8) are based on approximately 30,000 individuals and were obtained from the USDA 1977-78 Nationwide Food Consumption

Survey (USDA-NFCS). The food energy intakes were adjusted upwards by a constant factor of 1.2 for all individuals 9 years and older (Layton, 1993). This factor compensated for a consistent bias in USDA-NFCS attributed to under reporting of the foods consumed or the methods used to ascertain dietary intakes. Layton (1993) used a weighted average oxygen uptake of 0.05 L O_2/KJ which was determined from data reported in the 1977-78 USDA-NFCS and the second National Health and Nutrition Examination Survey (NHANES II). The survey sample for NHANES II was approximately 20,000 participants. The ventilatory equivalent (VQ) of 27 used was calculated as the geometric mean of VQ data that were obtained from several studies by Layton (1993).

The inhalation rate estimation techniques are shown in footnote (a) of Table 7-9. Table 7-9 presents the daily inhalation rate for each age/gender cohort. The highest daily inhalation rates were reported for children between the ages of 6-8 years (10 m^3/day), for males between 15-18 years (17 m^3/day), and females between 9-11 years (13 m^3/day). Inhalation rates were also calculated for active and inactive periods for the various age/gender cohorts.

The inhalation rate for inactive periods was estimated by multiplying the basal metabolic rate (BMR) times the oxygen uptake (H) times the VQ. BMR was defined as "the minimum amount of energy required to support basic cellular respiration while at rest and not actively digesting food" (Layton, 1993). The inhalation rate for active periods was calculated by multiplying the inactive inhalation rate by the ratio of the rate of energy expenditure during active hours to the estimated BMR. This ratio is presented as F in Table 7-9. These data for active and inactive inhalation rates are also presented in Table 7-9. For children, inactive and active inhalation rates ranged between 2.35 and 5.95 m^3/day and 6.35 to 13.09 m^3/day, respectively.

Second Approach

Inhalation rates were calculated by multiplying the BMR of the population cohorts times A (ratio of total daily energy expenditure to daily BMR) times H times VQ. The BMR data obtained from the literature were statistically analyzed and regression equations were developed to predict BMR from body weights of various age/gender cohorts (Layton, 1993). The statistical data used to develop the regression equations are presented in Appendix Table 7A-3. The data obtained from the second approach are presented in Table 7-10. Inhalation rates for children (6 months - 10 years) ranged from 7.3-9.3 m^3/day for male and 5.6 to 8.6 m^3/day for female children, and for older children (10-18 years), inhalation rates were 15 m^3/day for males and 12

m^3/day for females. These rates are similar to the daily inhalation rates obtained using the first approach. Also, the inactive inhalation rates obtained from the first approach are lower than the inhalation rates obtained using the second approach. This may be attributed to the BMR multiplier employed in the equation of the second approach to calculate inhalation rates.

Inhalation rates were also obtained for short-term exposures for various age/gender cohorts and five energy-expenditure categories (rest, sedentary, light, moderate, and heavy). BMRs were multiplied by the product of MET, H, and VQ. The data obtained for short term exposures are presented in Table 7-11.

The major strengths of the Layton (1993) study are that it obtains similar results using three different approaches to estimate inhalation rates in different age groups and that the populations are large, consisting of men, women, and children. Explanations for differences in results due to metabolic measurements, reported diet, or activity patterns are supported by observations reported by other investigators in other studies. Major limitations of this study are that activity pattern levels estimated in this study are somewhat subjective, the explanation that activity pattern differences is responsible for the lower level obtained with the metabolic approach (25 percent) compared to the activity pattern approach is not well supported by the data, and different populations were used in each approach which may introduce error.

7.3 RECOMMENDATIONS

The recommended inhalation rates for children are based on the studies described in this chapter. Different survey designs and populations were utilized in the studies described in this Chapter. Excluding the study by Layton (1993), the population surveyed in all of the studies described in this report were limited to the Los Angeles area. This regional population may not represent the general U.S. population and may result in biases. However, based on other aspects of the study design, these studies were selected as the basis for recommended inhalation rates.

The selection of inhalation rates to be used for exposure assessments depends on the age of the exposed population and the specific activity levels of this population during various exposure scenarios. The confidence ratings and recommended inhalation rates are presented in Tables 7-12 and 7-13, respectively. Based on the study results from Layton (1993), the recommended daily inhalation rate for infants (children less than 1 yr), during long-term dose assessments is 4.5 m^3/day. For children 1-2 years old, 3-5 years old, and 6-8 years old, the recommended daily inhalation rates are 6.8 m^3/day, 8.3 m^3/day, and 10 m^3/day, respectively. Recommended values for children aged 9-11 years are 14 m^3/day for males and 13 m^3/day for females. For children aged 12-14 years and 15-18 years, the recommended values are shown in Table 7-13.

Recommended short-term inhalation rates for children aged 18 years and under are also summarized in Table 7-13. The short-term inhalation rates were calculated by averaging the inhalation rates for each activity level from the various key studies (Table 7-14). The recommended average hourly inhalation rates are as follows: 0.3 m^3/hr during rest; 0.4 m^3/hr for sedentary activities; 1.0 m^3/hr for light activities; 1.2 m^3/hr for moderate activities; and 1.9 m^3/hr for heavy activities. The recommended short-term exposure data also include infants (less than 1 yr).

7.4 REFERENCES FOR CHAPTER 7

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Table 7-1. Calibration And Field Protocols For Self-monitoring of Activities Grouped by Subject Panels

Panel	Calibration Protocol	Field Protocol
Panel 2 - Healthy Elementary School Students - 5 male, 12 female, age 10-12	Outdoor exercises each consisted of 20 minute rest, slow walking, jogging and fast walking	Saturday, Sunday and Monday (school day) in early autumn; HR recordings and activity diary during waking hours and during sleep.
Panel 3 - Healthy High School Students - 7 male, 12 female, age 13-17	Outdoor exercises each consisted of 20 minute rest, slow walking, jogging and fast walking	Same as Panel 2, however, no HR recordings during sleep for most subjects.
Panel 6 - Young Asthmatics - 7 male, 6 female, age 11-16	Laboratory exercise tests on bicycles and treadmills	Similar to Panel 4, summer monitoring for 2 successive weeks, including 2 controlled exposure studies with few or no observable respiratory effects.

Source: Linn et al., 1992

Table 7-2. Subject Panel Inhalation Rates by Mean VR, Upper Percentiles, And Self-estimated Breathing Rates

	Inhalation Rates (m^3/hr)					
	N[a]	Mean VR (m^3/hr)	99th Percentile VR	Mean VR at Activity Levels (m^3/hr)[b]		
Panel				Slow	Medium	Fast
Healthy						
2 - Elementary School Students	17	0.90	1.98	0.84	0.96	1.14
3 - High School Students	19	0.84	2.22	0.78	1.14	1.62
Asthmatics						
6 - Elementary and High School Students	13	1.20	2.40	1.20	1.20	1.50

[a]Number of individuals in each survey panel.
[b]Some subjects did not report medium and/or fast activity. Group means were calculated from individual means (i.e., give equal weight to each individual who recorded any time at the indicated activity level).

Source: Linn et al. (1992).

Table 7-3. Distribution of Predicted Intake Rates by Location And Activity Levels For Elementary And High School Students

Age (yrs)	Student	Location	Activity Level	% Recorded Time[a]	Inhalation Rates (m^3/hr) Mean ± SD	Percentile Rankings[b] 1st	50th	99.9th
10-12	Elc (n[d]=17)	Indoors	slow	49.6	0.84 ± 0.36	0.18	0.78	2.34
			medium	23.6	0.96 ± 0.42	0.24	0.84	2.58
			fast	2.4	1.02 ± 0.60	0.24	0.84	3.42
		Outdoors	slow	8.9	0.96 ± 0.54	0.36	0.78	4.32
			medium	11.2	1.08 ± 0.48	0.24	0.96	3.36
			fast	4.3	1.14 ± 0.60	0.48	0.96	3.60
13-17	HS[c] (n[d]=19)	Indoors	slow	70.7	0.78 ± 0.36	0.30	0.72	3.24
			medium	10.9	0.96 ± 0.42	0.42	0.84	4.02
			fast	1.4	1.26 ± 0.66	0.54	1.08	6.84[c]
		Outdoors	slow	8.2	0.96 ± 0.48	0.42	0.90	5.28
			medium	7.4	1.26 ± 0.78	0.48	1.08	5.70
			fast	1.4	1.44 ± 1.08	0.48	1.02	5.94

[a]Recorded time averaged about 23 hr per elementary school student and 33 hr. per high school student, over 72-hr. periods.
[b]Geometric means closely approximated 50th percentiles; geometric standard deviations were 1.2-1.3 for HR, 1.5-1.8 for VR.
[c]EL = elementary school student; HS = high school student.
[d]N = number of students that participated in survey.
[e]Highest single value.

Source: Spier et al. (1992).

Table 7-4. Average Hours Spent Per Day in a Given Location and Activity Level For Elementary (EL) and High School (HS) Students

Student (EL[a], n[c]=17; HS[b], N[c]=19)	Location	Activity Level Slow	Medium	Fast	Total Time Spent (hrs/day)
EL	Indoor	16.3	2.9	0.4	19.6
EL	Outdoor	2.2	1.7	0.5	4.4
HS	Indoor	19.5	1.5	0.2	21.2
HS	Outdoor	1.2	1.3	0.2	2.7

[a]Elementary school (EL) students were between 10-12 years old.
[b]High school (HS) students were between 13-17 years old.
[c]N corresponds to number of school students.

Source: Spier et al. (1992).

Table 7-5. Distribution Patterns of Daily Inhalation Rates For Elementary (EL) And High School (HS) Students Grouped by Activity Level

Students	Age (yrs)	Location	Activity type[a]	Mean IR[b] (m^3/day)	Percentile Rankings 1st	50th	99.9th
EL	10-12	Indoor	Light	13.7	2.93	12.71	38.14
(n[c]=17)			Moderate	2.8	0.70	2.44	7.48
			Heavy	0.4	0.096	0.34	1.37
EL		Outdoor	Light	2.1	0.79	1.72	9.50
			Moderate	1.84	0.41	1.63	5.71
			Heavy	0.57	0.24	0.48	1.80
HS	13-17	Indoor	Light	15.2	5.85	14.04	63.18
(n=19)			Moderate	1.4	0.63	1.26	6.03
			Heavy	0.25	0.11	0.22	1.37
HS		Outdoor	Light	1.15	0.50	1.08	6.34
			Moderate	1.64	0.62	1.40	7.41
			Heavy	0.29	0.096	0.20	1.19

[a]For this report, activity type presented in Table 7-2 was redefined as light activity for slow, moderate activity for medium, and heavy activity for fast.
[b]Daily inhalation rate was calculated by multiplying the hours spent at each activity level (Table 7-4) by the corresponding inhalation rate (Table 7-3).
[c]Number of elementary (EL) and high school students (HS).

Source: Adapted from Spier et al. (1992) (Generated using data from Tables 7-3 and 7-4).

Table 7-6. Summary of Average Inhalation Rates (M^3/hr) by Age Group And Activity Levels For Laboratory Protocols

Age Group	Resting[a]	Sedentary[b]	Light[c]	Moderate[d]	Heavy[e]
Young Children[f]	0.37	0.40	0.65	DNP[g]	DNP
Children[h]	0.45	0.47	0.95	1.74	2.23

[a]Resting defined as lying (see Appendix Table 7A-1 for original data).
[b]Sedentary defined as sitting and standing (see Appendix Table 7A-1 for original data).
[c]Light defined as walking at speed level 1.5 - 3.0 mph (see Appendix Table 7A-1 for original data).
[d]Moderate defined as fast walking (3.3 - 4.0 mph) and slow running (3.5 - 4.0 mph) (see Appendix Table 7A-1 for original data).
[e]Heavy defined as fast running (4.5 - 6.0 mph) (see Appendix Table 7A-1 for original data).
[f]Young children (both genders) 3 - 5.9 yrs old.
[g]DNP. Group did not perform this protocol or N was too small for appropriate mean comparisons. All young children did not run.
[h]Children (both genders) 6 - 12.9 yrs old.

Source: Adapted from Adams (1993).

Table 7-7. Summary of Average Inhalation Rates (M^3/hr) by Age Group And Activity Levels in Field Protocols

Age Group	Light[a]	Sedentary[b]	Moderate[c]
Young Children[d]	DNP[e]	DNP	0.68
Children[f]	DNP	DNP	1.07

[a]Light activity was defined as car maintenance (males), housework (females), and yard work (females) (see Appendix Table 7A-2 for original data).
[b]Sedentary activity was defined as car driving and riding (both genders) (see Appendix Table 7A-2 for original data).
[c]Moderate activity was defined as mowing (males); wood working (males); yard work (males); and play (children) (see Appendix Table 7A-2 for original data).
[d]Young children (both genders) = 3 - 5.9 yrs old.
[e]DNP. Group did not perform this protocol or N was too small for appropriate mean comparisons.
[f]Children (both genders) = 6 - 12.9 yrs old.

Source: Adams (1993).

Table 7-8. Comparisons of Estimated Basal Metabolic Rates (BMR) With Average Food-energy Intakes For Individuals Sampled in The 1977-78 NFCS

Cohort/Age (years)	Body Weight kg	BMR[a] MJ d^{-1}[b]	BMR[a] kcal d^{-1}[c]	Energy Intake (EFD) MJ d^{-1}	Energy Intake (EFD) kcal d^{-1}	Ratio EFD/BMR
Children						
Under 1	7.6	1.74	416	3.32	793	1.90
1 to 2	13	3.08	734	5.07	1209	1.65
3 to 5	18	3.69	881	6.14	1466	1.66
6 to 8	26	4.41	1053	7.43	1774	1.68
Males						
9 to 11	36	5.42	1293	8.55	2040	1.58
12 to 14	50	6.45	1540	9.54	2276	1.48
15 to 18	66	7.64	1823	10.8	2568	1.41
Females						
9 to 11	36	4.91	1173	7.75	1849	1.58
12 to 14	49	5.64	1347	7.72	1842	1.37
15 to 18	56	6.03	1440	7.32	1748	1.21

[a]Calculated from the appropriate age and gender-based BMR equations given in Appendix Table 7A-3.
[b]MJ d^{-1} - mega joules/day
[c]kcal d^{-1} - kilo calories/day

Source: Layton (1993).

Table 7-9. Daily Inhalation Rates Calculated From
Food-energy Intakes

Cohort/Age (years)	L[d]	Daily Inhalation Rate[a] (m^3/day)	(h)Sleep (h)	MET[b] Value A[e]	MET[b] Value F[f]	Inhalation Rates Inactive[c] (m^3/day)	Inhalation Rates Active[c] (m^3/day)
Children							
<1	1	4.5	11	1.9	2.7	2.35	6.35
1 - 2	2	6.8	11	1.6	2.2	4.16	9.15
3 - 5	3	8.3	10	1.7	2.2	4.98	10.96
6 - 8	3	10	10	1.7	2.2	5.95	13.09
Males							
9 - 11	3	14	9	1.9	2.5	7.32	18.3
12 - 14	3	15	9	1.8	2.2	8.71	19.16
15 - 18	4	17	8	1.7	2.1	10.31	21.65
Females							
9 - 11	3	13	9	1.9	2.5	6.63	16.58
12 - 14	3	12	9	1.6	2.0	7.61	15.20
15 - 18	4	12	8	1.5	1.7	8.14	13.84

[a]Daily inhalation rate was calculated by multiplying the EFD values (see Table 7-10) by H x VQ x (m^3 1,000 L^{-1}) for subjects under 9 years of age and by 1.2 x H x VQ x (m^3 1,000 L^{-1}) (for subjects 9 years of age and older (see text for explanation).

Where:

EFD = Food energy intake (Kcal/day) or (MJ/day)

H = Oxygen uptake = 0.05 LO_2/KJ or 0.21 LO_2/Kcal

VQ = Ventilation equivalent = 27 = geometric mean of VQs (unitless)

[b]MET = Metabolic equivalent

[c]Inhalation rate for inactive periods was calculated as BMR x H x VQ x (d 1,440 min^{-1}) and for active periods by multiplying inactive inhalation rate by F (See footnote f); BMR values are from Table 7-10.

Where:

BMR = Basal metabolic rate (MJ/day) or (kg/hr)

[d]L is the number of years for each age cohort.

[e]For individuals 9 years of age and older, A was calculated by multiplying the ratio for EFD/BMR (unitless) (Table 7-10) by the factor 1.2 (see text for explanation).

[f]F = (24A - S)/(24 - S) (unitless), ratio of the rate of energy expenditure during active hours to the estimated BMR (unitless)

Where:

S = Number of hours spent sleeping each day (hrs)

Source: Layton (1993).

Table 7-10. Daily Inhalation Rates Obtained From The Ratios Of Total Energy Expenditure to Basal Metabolic Rate (BMR)

Gender/Age (yrs)	Body Weight[a] (kg)	BMR[b] (MJ/day)	VQ	A[c]	H (m^3O_2/MJ)	Inhalation Rate, V_E (m^3/day)[d]
Male						
0.5 - <3	14	3.4	27	1.6	0.05	7.3
3 - <10	23	4.3	27	1.6	0.05	9.3
10 - <18	53	6.7	27	1.7	0.05	15
Female						
0.5 - <3	11	2.6	27	1.6	0.05	5.6
3 - <10	23	4.0	27	1.6	0.05	8.6
10 - <18	50	5.7	27	1.5	0.05	12

[a]Body weight was based on the average weights for age/gender cohorts in the U.S. population.

[b]The BMRs (basal metabolic rate) are calculated using the respective body weights and BMR equations (see Appendix Table 7A-3).

[c]The values of the BMR multiplier (EFD/BMR) for those 18 years and older were derived from the Basiotis et al. (1989) study: Male = 1.59, Female = 1.38. For males and females under 10 years old, the mean BMR multiplier used was 1.6. For males and females aged 10 to < 18 years, the mean values for A given in Table 7-11 for 12-14 years and 15-18 years, age brackets for males and females were used: male = 1.7 and female = 1.5.

[d]Inhalation rate = BMR x A x H x VQ; VQ = ventilation equivalent and H = oxygen uptake.

Source: Layton (1993).

Table 7-11. Inhalation Rates For Short-term Exposures

			Activity Type				
			Rest	Sedentary	Light	Moderate	Heavy
			MET (BMR Multiplier)				
			1	1.2	2[c]	4[d]	10[e]
Gender/Age (yrs)	Weight (kg)[a]	BMR[b] (MJ/day)	Inhalation Rate (m^3/hr)[f,g]				
Male							
0.5 - <3	14	3.40	0.19	0.23	0.38	0.78	1.92
3 - <10	23	4.30	0.24	0.29	0.49	0.96	2.40
10 - <18	53	6.70	0.38	0.45	0.78	1.50	3.78
Female							
0.5 - <3	11	2.60	0.14	0.17	0.29	0.60	1.44
3 - <10	23	4.00	0.23	0.27	0.45	0.90	2.28
10 - <18	50	5.70	0.32	0.38	0.66	1.26	3.18

[a]Body weights were based on average weights for age/gender cohorts of the U.S. population

[b]The BMRs for the age/gender cohorts were calculated using the respective body weights and the BMR equations (Appendix Table 7A-3).

[c]Range of 1.5 - 2.5.

[d]Range of 3 - 5.

[e]Range of >5 - 20.

[f]The inhalation rate was calculated by multiplying BMR (MJ/day) x H (0.05 L/KJ) x MET x VQ (27) x (d/1,440 min)

[g]Original data were presented in L/min. Conversion to m^3/hr was obtained as follows: $\frac{60\ \text{min}}{\text{hr}} \times \frac{m^3}{1000\text{L}} \times \frac{\text{L}}{\text{min}}$

Source: Layton (1993).

Table 7-12. Confidence in Inhalation Rate Recommendations

Considerations	Rationale	Rating
Study Elements		
• Peer Review	Studies are from peer reviewed journal articles and an EPA peer reviewed report.	High
• Accessibility	Studies in journals have wide circulation. EPA reports are available from the National Technical Information Service.	High
• Reproducibility	Information on questionnaires and interviews were not provided.	Medium
• Focus on factor of interest	Studies focused on ventilation rates and factors influencing them.	High
• Data pertinent to U.S.	Studies conducted in the U.S.	High
• Primary data	Both data collection and re-analysis of existing data occurred.	Medium
• Currency	Recent studies were evaluated.	High
• Adequacy of data collection period	Effort was made to collect data over time.	High
• Validity of approach	Measurements were made by indirect methods.	Medium
• Representativeness of the population	An effort has been made to consider age and gender, but not systematically. Sample size was too small.	Medium
• Characterization of variability	An effort has been made to address age and gender, but not systematically.	High
• Lack of bias in study design	Subjects were selected randomly from volunteers and measured in the same way.	High
• Measurement error	Measurement error is well documented by statistics, but procedures measure factor indirectly.	Medium
Other Elements		
• Number of studies	Five key studies and six relevant studies were evaluated.	
• Agreement between researchers	There is general agreement among researchers using different experimental methods.	High
Overall Rating	Several studies exist that attempt to estimate inhalation rates according to age, gender and activity.	**Medium**

Table 7-13. Summary of Recommended Values For Inhalation

Population	Mean	Upper Percentile
Long-term Exposures		
Infants		
<1 year	4.5 m^3/day	---
Children		
1-2 years	6.8 m^3/day	---
3-5 years	8.3 m^3/day	---
6-8 years	10 m^3/day	---
9-11 years		
males	14 m^3/day	---
females	13 m^3/day	---
12-14 years		
males	15 m^3/day	---
females	12 m^3/day	---
15-18 years		
males	17 m^3/day	---
females	12 m^3/day	---
Short-term Exposures		
Children (18 years and under)		
Rest	0.3 m^3/hr	---
Sedentary Activities	0.4 m^3/hr	---
Light Activities	1.0 m^3/hr	---
Moderate Activities	1.2 m^3/hr	---
Heavy Activities	1.9 m^3/hr	---

Table 7-14. Summary of Children's Inhalation Rates
For Short-Term Exposure Studies

Arithmetic Mean (m^3/hr)					
Activity Level					
Rest	Sedentary	Light	Moderate	High	Reference
0.4	0.4	0.8	--	--	Adams, 1993 (Lab protocols)
--	--	--	0.9	--	Adams, 1993 (Field protocols)
0.2	0.3	0.5	1.0	2.5	Layton, 1993 (Short-term data)
--	--	1.8	2.0	2.2	Spier et al., 1992 (10-12 yrs)
--	--	0.8	1.0	11	Linn et al., 1992 (10-12 yrs)

APPENDIX 7A

VENTILATION DATA

TABLE 7A-1. Mean Minute Ventilation (V_e, L/min) by Group And Activity for Laboratory Protocols

Activity		Young Children[a]	Children
Lying		6.19	7.51
Sitting		6.48	7.28
Standing		6.76	8.49
Walking	1.5 mph	10.25	DNP
	1.875 mph	10.53	DNP
	2.0 mph	DNP	14.13
	2.25 mph	11.68	DNP
	2.5 mph	DNP	15.58
	3.0 mph	DNP	17.79
	3.3 mph	DNP	DNP
	4.0 mph	DNP	DNP
Running	3.5 mph	DNP	26.77
	4.0 mph	DNP	31.35
	4.5 mph	DNP	37.22
	5.0 mph	DNP	DNP
	6.0 mph	DNP	DNP

[a]Young Children, male and female 3-5.9 yr olds; Children, male and female 6-12.9 yr olds; Adult Females, adolescent, young to middle-aged, and older adult females; Adult Males, adolescent, young to middle-aged, and older adult males; DNP, group did not perform this protocol or N was too small for appropriate mean comparisons

Source: Adams (1993).

TABLE 7A-2. Mean Minute Ventilation (V_e, L/min) by Group and Activity for Field Protocols

Activity	Young Children[a]	Children
Play	11.31	17.89
Car Driving	DNP	DNP
Car Riding	DNP	DNP
Yardwork	DNP	DNP
Housework	DNP	DNP
Car Maintenance	DNP	DNP
Mowing	DNP	DNP
Woodworking	DNP	DNP

[a]Young Children, male and female 3-5.9 yr olds; Children, male and female 6-12.9 yr olds; Adult Females, adolescent, young to middle-aged, and older adult females; Adult Males, adolescent, young to middle-aged, and older adult males; DNP, group did not perform this protocol or N was too small for appropriate mean comparisons;

Source: Adams (1993).

TABLE 7A-3. Statistics of the Age/gender Cohorts Used To Develop Regression Equations for Predicting Basal Metabolic Rates (BMR)

Gender/Age (y)	BMR MJ d^{-1}	±SD	CV[a]	Body Weight (kg)	N[b]	BMR Equation[c]	r[d]
Males							
Under 3	1.51	0.918	0.61	6.6	162	0.249 bw - 0.127	0.95
3 to < 10	4.14	0.498	0.12	21	338	0.095 bw + 2.110	0.83
10 to < 18	5.86	1.171	0.20	42	734	0.074 bw + 2.754	0.93
Females							
Under 3	1.54	0.915	0.59	6.9	137	0.244 bw - 0.130	0.96
3 to < 10	3.85	0.493	0.13	21	413	0.085 bw + 2.033	0.81
10 to < 18	5.04	0.780	0.15	38	575	0.056 bw + 2.898	0.8

[a]Coefficient of variation (SD/mean)
[b]N = number of subjects
[c]Body weight (bw) in kg
[d]coefficient of correlation

Source: Layton (1993).